Prediction of the Low Frequency Wave Field on Open Coastal Beaches

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LONG-TERM GOALS

The long-term goal of this study is to arrive at a predictive understanding of the time varying circulation in the nearshore region given only information about the incident wave field and bottom bathymetry. Predictions should include information about the kinematics of low frequency motions (their wavenumbers and frequencies) as well as information about their dynamics (energetics).

OBJECTIVES

The scientific objectives of the study are related to gaining an understanding of the important features of the nearshore circulation field, so that quantitative predictions about the circulation field at a given site can be reliably made. Specific objectives include: 1. The assessment of the impact of specific features of wave groups on edge wave development and the prediction of the finite amplitude edge wave field resulting from a balance between the wave group forcing and dissipation mechanisms. 2. The assessment of the degree to which non-uniformities in the bottom bathymetry (both abrupt and gradual) affect the resulting low frequency wave climate. 3. The assessment of the importance of interactions between different modes of time-varying motions in the nearshore region, as well as interactions between these modes and the incident wave field. 4. To arrive at a predictive understanding of low frequency motions.

APPROACH

The approach is to use a numerical model to assess our understanding of time-varying circulation in the nearshore region. The finite amplitude behavior of low frequency motions in the nearshore region is a function of a balance between processes that generate these motions and processes that dissipate them. The approach used here is to isolate several generation, dissipation as well as evolution processes in a modeling effort and start with the simplest possible theory to model the processes. More complicated and full treatments are introduced in a step-by-step fashion resulting in an understanding of the effects of the processes and their parameterizations on the resulting circulation field. In the final stages of the project we will test our predictive capabilities by simulating the actual situation during the DELILAH field experiment. Measurements will be used to specify the incident wave forcing function and bathymetry. The computed time-varying circulation field will be compared to measurements.

We are utilizing a model that solves the time-dependent shallow water equations with additional terms to account for the effects of forcing and damping. Although only valid in shallow water, these

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equations can model the leading order behavior of both low frequency gravity motions (edge waves) and vorticity motions (shear waves). Eight partial differential equations are solved simultaneously to obtain the evolution of eight unknowns; namely, the phase-averaged water surface elevation, the phase-averaged cross-shore and longshore velocities, the horizontal shoreline runup, the incident wave energy, the incident wave wavenumber, the local incident wave direction, and the water depth. The effects of bottom friction, turbulent momentum mixing, incident wave transformation and forcing, wave-current interaction and arbitrary bottom movement, are included in a rudimentary fashion. However, we begin our modeling effort by generating edge waves and shear waves in idealized conditions, and progressively move to realistic situations where these motions are allowed to coexist and interact.

WORK COMPLETED

Since the generation of finite amplitude behavior of shear waves has already been studied using the model at hand, we have, at first, concentrated on the generation of forced-damped edge waves through a resonant forcing mechanism. According to this idea, if two incident waves with slightly different frequencies approach the shore they form a wave group, and the difference interactions between the waves cause temporal and spatial variations in the radiation stress forcing that are at infragravity scales. If the time and length scales of these variations correspond to the time and length scales of an edge waves mode, that mode can be resonantly forced. The equilibrium finite amplitude of this mode is dictated by the strength of the forcing (groupiness) and the strength of the damping (friction). We have completed the implementation of an equation governing the behavior of the time-varying incident wave energy in order to simulate the evolution of incoming wave groups. The bi-chromatic forcing mechanism was found to be successful in generating edge waves of finite amplitude.

Shear instabilities of the longshore current had previously been studied in detail on both plane and barred beaches using the present model. For realistic conditions we had found that the surf zone longshore current developed undulations that often resulted in strong, offshore directed current components and vortex pairs. Offshore directed currents can significantly alter the incident wave field and can, therefore, also alter the nature of the forcing of the longshore current. This feedback mechanism has so far been neglected, but may give rise to a significantly different shear wave field than predicted by models that neglect the wave-current interaction process. We are utilizing the time dependent equations that approximate the behavior of phase-averaged properties of the incident waves; namely, the incident wave energy, the wavenumber and the local angle of incidence. The energy equation for the incident waves is used to model the former while the conservation of wavenumber principle is introduced to model the latter two variables. These model equations include effects of the current velocities. In this manner the forcing of wave-induced currents is modeled while taking the effects of the generated currents on the wave field into account.

RESULTS

Results have been obtained in relation to forced-damped edge waves as well as wave-current interaction effects on shear waves. Figure 1(a) shows a snapshot of the wave height associated with a bi-chromatic wave field on a plane beach. The shoreline is located at x=0 and x points offshore while y points alongshore. The variation of the wave height in space is readily observed. The waves break approximately 20 m offshore, but the location of breaking is a function of both space and time.

Figure 1(b) shows a snapshot of the phase-averaged water surface elevation. Offshore of the breakpoint a bound long wave can be observed. It is phase-locked to the wave height variations. Shoreward of the breakpoint amplification of a mode zero edge wave is evident. We have carried out several simulations and have found that the equilibrium amplitude of the resulting edge wave is a direct function of the strength of the grouping in the incident wave field as well as the amount of bottom friction.

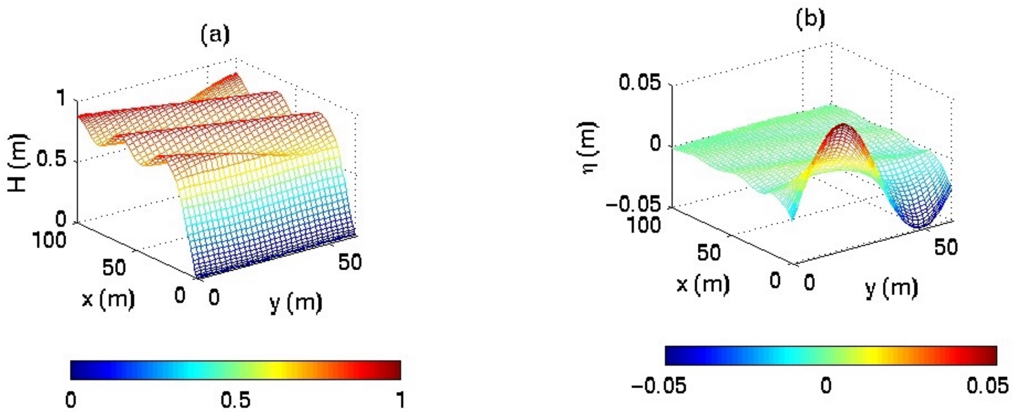

Figure 1: Snapshot of (a) incident wave height and (b) phase-averaged water surface elevation.

We have chosen the heights of the two individual incident waves such that the total wave height varies by a maximum amplitude of 10%. This variation is characterized by the parameter δ which is equal to 0.1 in this case. Note that this parameter is a scale for the groupiness of the incident waves and, hence, the strength of the forcing mechanism. The damping is included through bottom friction. The strength of the damping effect is characterized by a friction coefficient c_f. Figure 2 show the equilibrium amplitudes of edge waves generated for a range of δ and c_f-values. The results show that the equilibrium amplitude increases with increasing groupiness (δ) and decreasing friction (c_f). However, an interesting conclusion can be drawn by observing that the same equilibrium amplitude can be achieved with a combination of strong forcing and strong dissipation or with a combination of weak forcing and weak dissipation. Observed edge waves governed by a regime that obeys the former balance would have to be locally generated and would dissipate quickly once the forcing ceased, whereas edge waves that obey the latter regime would exist for long periods of time even after the resonant forcing mechanism terminates. These results show that the accurate prediction of edge wave amplitudes requires independent estimates of both the groupiness intensity as well as the bottom friction.

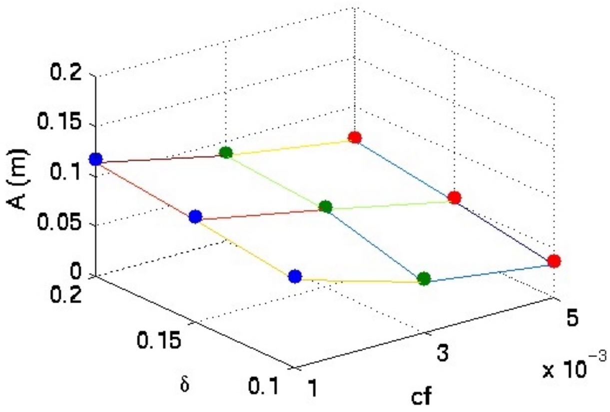

Figure 2: Edge wave amplitude as a function of the group strength δ and friction coefficient c_f.

Computations of the instability field for a barred beach show that the shear instabilities of the longshore current have a significantly altered finite amplitude behavior when wave-current interaction effects are included. Figure 3(a) shows a snapshot of the vorticity field when wave-current interaction is neglected. The shoreline is once again located at x=0 and x points offshore while y points alongshore. The nearshore bar is located 100 m offshore of the shoreline, and the shear waves can be observed to affect a region that extends about 200 m offshore. There are also areas over the bar (e.g. around y=350 m) where offshore directed currents can be observed. These currents can exceed 0.3 m/s. Figure 3(b) shows a snapshot of the vorticity field obtained while including wave-current interaction. The primary effect of the interactions is a reduction of the extent of the motions in the offshore direction. The energy content of the motions within two surf zone widths is not significantly altered but the general character of the flow features appears to be strongly affected by the inclusion of wave-current interaction.

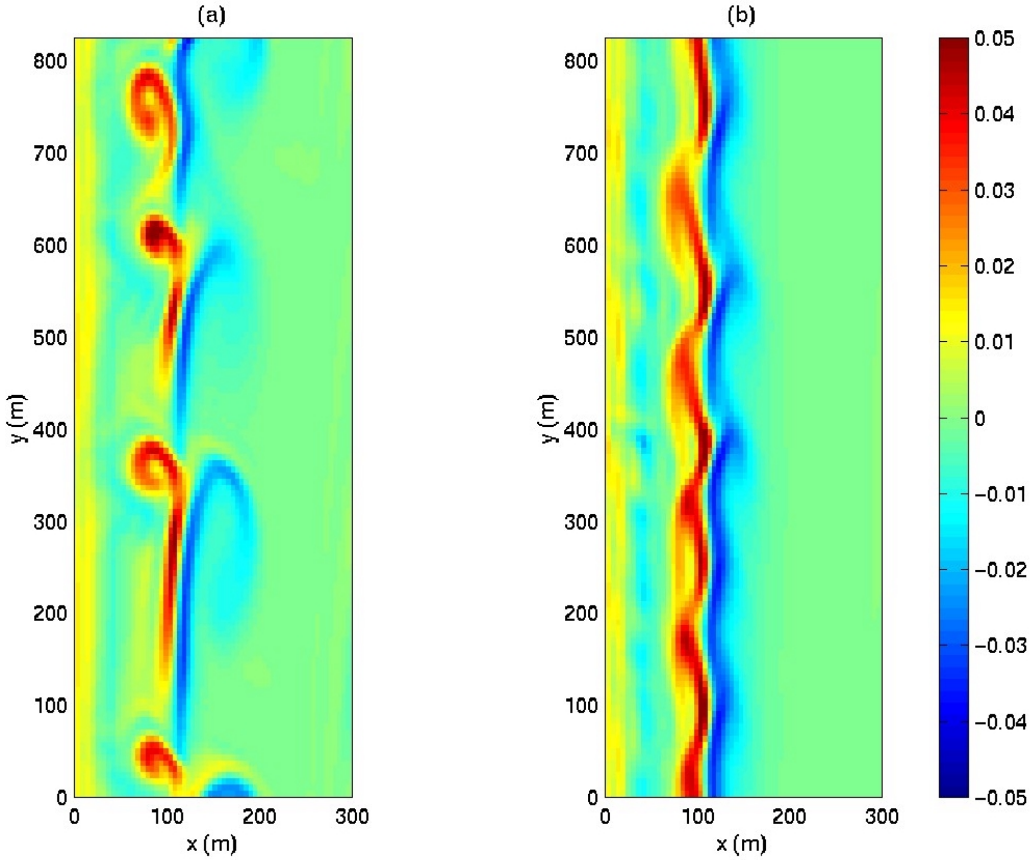

Figure 3: Snapshots of vorticity for shear instabilities on a barred beach (a) neglecting and (b) including wave-current interaction.

A second effect of wave-current interaction is that the resulting flow features have a faster propagation speed as can be seen in Figure 4.These results indicate that a previously neglected effect may be of primary importance to the prediction of the circulation in the nearshore region.

IMPACT/APPLICATIONS

This study will shed light on the processes that are important in the low frequency range of the energy spectrum, such as interactions between low frequency waves and response of the low frequency environment to external forcing. This study can also serve as a benchmark for other studies that do not explicitly resolve the time-varying low frequency wave field but instead focus only on the mean circulation. Results obtained here should also be relevant to studies that are not restricted to low frequency motions, but where the low frequency motions are embedded in higher frequency oscillations, making the processes difficult to identify.

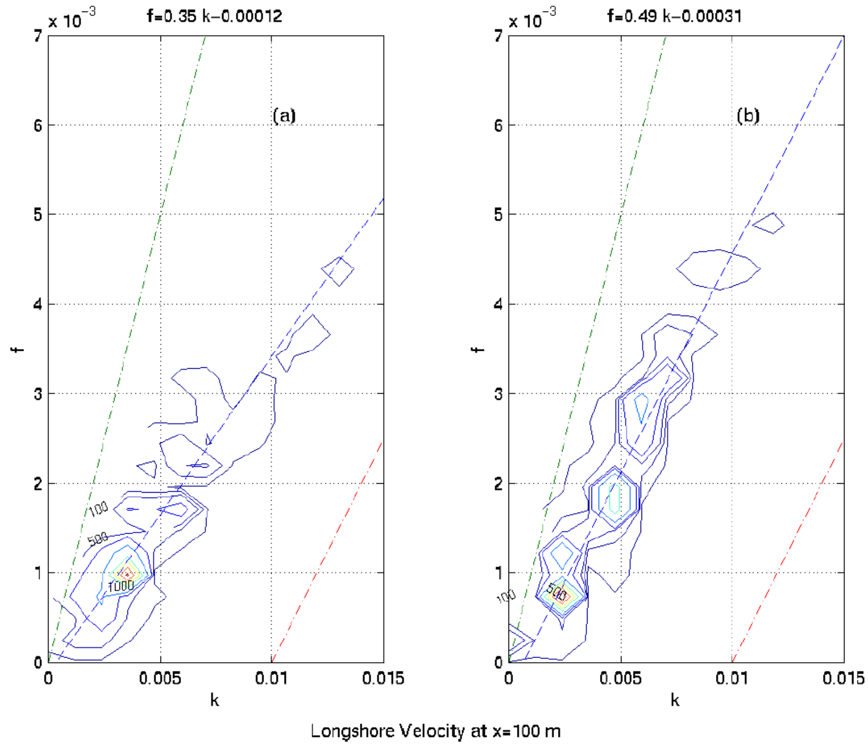

Figure 4: Frequency-longshore wavenumber spectra (a) neglecting and (b) including wave-current interaction. The equation for the best fit line is shown above each plot.

TRANSITIONS

The work on the project will lead to a robust modeling tool which is capable of predicting the time-varying circulation field including effects such as incident wave forcing, bottom friction, momentum mixing and wave-current interaction. The model code is available to the engineering and science communities.

RELATED PROJECTS

The effect of edge waves and shear waves on the evolution of bathymetry is being investigated as part of the ongoing NOPP project (Lead P.I. J.T. Kirby) "Development and Verification of a Comprehensive Community Model for Physical Processes in the Nearshore Ocean".